The nature of baryon resonances in the chiral unitary approach

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Chiral symmetry is one of the guiding principles to study hadron physics based on the underlying theory of QCD. The spontaneous breakdown of the chiral symmetry $SU(N_f) \times SU(N_f) \rightarrow SU(N_f)$ in the light flavor sector provides low energy theorems which govern the dynamics of the Nambu-Goldstone bosons at low energies. The systematic expansion in powers of the small momenta is the chiral perturbation theory. Recent developments have shown that unitarized S-matrix constructed in a way consistent with the chiral perturbation theory at low energy can describe also some resonances very well. This provides an intuitive picture for the resonances possessing a molecular like structure of the scattering hadrons. A typical example is the $\Lambda(1405)$ which turns out to be composed of two dominant components of $\bar{K}N$ and $\pi\Sigma$ [1, 2].

When the S (T)-matrix is constructed, we need to handle the ambiguity associated with the renormalization of higher order quantum effects. In a scattering theory in which the potential V is given, this appears in the evaluation of the Green's function $G(\sqrt{s})$ in intermediate states. In an equivalent method of the dispersion theory, that appears as a subtraction constant in the integral over spectral densities along discontinuities of the amplitude. From a more general point, the ambiguity is associated with the arbitrariness of the separation of V and $G(\sqrt{s})$, which can be fixed under a suitable renormalization condition.

Recently we have discussed that the ambiguity can be related to the nature of the resonance [3]. In order to validate the interpretation of a resonance as having a molecular like structure of constituent hadrons, we propose to define a natural regularization scheme based on the scattering theory with the potential of leading term of the low energy theorem. This is the Weinberg-Tomozawa interaction which plays a dominant role for s-wave scattering at low energy. The natural regularization scheme can remove the above ambiguity and determine the subtraction constant (so called a-parameter) uniquely. If such a framework can generate a resonance in a way consistent with the observed resonance, we regard the resonance as a dynamically generated one having the molecular like structure.

On the other hand, a-parameter can be also determined so as to reproduce observed resonances. Thus determined a may be different from the naturally determined one. We have then shown that the difference between the two parameters can be interpreted as an interaction in addition to the original Weinberg-Tomozawa interaction. We find that the new interaction can be expressed as a pole term of an effective mass M_{eff}, reminiscent to the CDD pole.

We have applied this method to the two systems for $\Lambda(1405)$ and $N(1535)$ which are resonances of s-wave meson-baryon scattering. We find that the natural renormalization scheme can explain well $\Lambda(1405)$ with the pole term of only the negligible strength, while we need it with non-negligible strength for $N(1535)$. The strength of the pole term is controlled by the effective mass M_{eff}; for $\Lambda(1405)$ it is as large as 8 GeV while for $N(1535)$ it is of the same order of the resonance mass ~ 1.7 GeV.

The present analysis can be applied to any systems described by the chiral unitary approach. We have also emphasized the importance of the phenomenological fitting to the data, otherwise we cannot extract the correct low energy structure which is necessary to interpret the origin of the resonance. Hence, precise determination of the meson-hadron scattering data will enable us to study more about the properties of the hadron resonances.

References

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